Solution. In figuring the heat loss from Equation 2, it is necessary to first make an assumption for the outer surface temperature t_2 and the temperature between the diatomaceous silica and 85 per cent magnesia insulation, so that the mean temperature of each material can be obtained and the thermal conductivity corresponding to the mean temperature of each material substituted in the formula. First assume an outer surface temperature of 140 F and a temperature of 570 F between the two materials corresponding to a mean temperature of (1200 + 570) ÷ 2 or 885 F for the diatomaceous silica and (570 + 140) ÷ 2 or 355 F for the 85 per cent magnesia insulation. The conductivities of these two materials at mean temperatures of 885 and 355 F interpolated from Table 6 are 0.865 and 0.5 Btu, respectively.

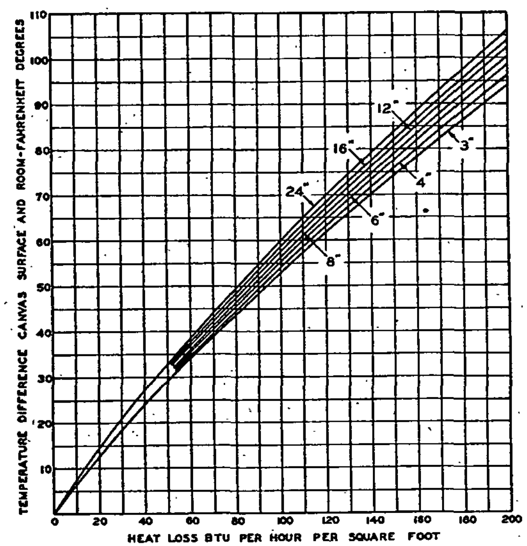

FIG. 4. HEAT LOSS FROM CANVAS-COVERED CYLINDRICAL SURFACES OF VARIOUS DIAMETERS

These values are substituted in Equation 2 and a trial calculation made. For a nominal 6-in. steel pipe $r_1 = 3.312$, $r_2 = 6.312$ and $r_3 = 8.312$ then,

$$q_0 = \frac{1200 - 140}{\dfrac{8.312 \log_e \dfrac{6.312}{3.312}}{0.865} + \dfrac{8.312 \log_e \dfrac{8.312}{6.312}}{0.5}} = \frac{1060}{6.2 + 4.58} = 98.3 \text{ Btu.}$$

The temperature drop from the outer surface of the insulation to the surrounding air for a heat loss of 98.3 Btu is found from Fig. 4 to be 57 F for a 16-in. O.D. cylindrical surface, or 57 + 80 F room temperature = 137 F surface temperature. Since a surface temperature of 140 F was assumed, it is evident that a temperature closer to 137 F, or, for instance, 138 F should be used for recalculation:

$$q_0 = \frac{1200 - 138}{6.2 + 4.58} = 98.4 \text{ Btu.}$$

Since the temperature drop through each material is equal to the heat flow times the actual resistance of each material, the temperature drop through the diatomaceous silica is 98.4 × 6.2 = 610 F, or the temperature between the two insulating materials

is (1200 − 610) = 590 F. Since a temperature of 570 F between the two materials was assumed, it is obvious that a temperature closer to 590, or for instance 586 F may be selected. The mean temperatures of the two insulations corresponding to the new assumptions are (1200 + 586) ÷ 2 = 893 and (586 + 138) ÷ 2 = 362, and the interpolated conductivities corresponding to the new mean temperatures are 0.87 and 0.505 for the diatomaceous silica and 85 per cent magnesia, respectively. By substituting in Equation 2:

$$q_0 = \frac{1200 - 138}{\dfrac{5.36}{0.87} + \dfrac{2.29}{0.505}} = \frac{1062}{6.16 + 4.53} = 99.3 \text{ Btu.}$$

Again referring to Fig. 4, it is seen that the temperature drop from the outer surface of the insulation to the surrounding air for a heat loss of 99.3 Btu = 58 F, which corresponds to the surface temperature of 138 F last assumed. The temperature drop through the diatomaceous silica is 99.3 × 6.16 = 612 F, corresponding to a temperature of 588 F between the two materials, which checks very closely with the temperature of 585 F last assumed. The heat loss is therefore 99.3 × 8.312 ÷ 3.312 or 249 Btu per sq ft of pipe surface. Since the surface area per linear foot of 6-in. pipe is 1.734 sq ft (Table 3), the heat loss per linear foot of pipe will be 249 × 1.734 = 432 Btu per hr.

The rate of heat loss from a surface maintained at constant temperature is greatly increased by air circulation over the surface. In the case of well-insulated surfaces, the increases in losses due to air velocity are very small as compared with increases from bare surfaces, because of the fact that air flowing over the surface of the insulation can increase only the conductance of heat from surface to air, and cannot change the internal conductance of the insulation itself. The maximum increase in heat loss due to air velocity ranges from about 15 per cent in the case of 1-in. thick insulation, to about 5 per cent in the case of 3-in. thick insulation, provided that the insulation is thoroughly sealed so that air can flow only over the surface. If the conditions are such that the air may circulate through cracks and crevices in the insulation, the increases may be far greater than those given. Therefore, it is essential that insulation be applied in such a manner that air circulation within it or between it and the pipe is avoided.

Fig. 4 shows the loss of heat from canvas-covered, cylindrical surfaces of various outside diameters when the surface to air temperature difference is low. The data are from tests made at Mellon Institute.

The frequent practice of omitting insulation on that portion of a pipe which passes through a masonry wall, or which may be in contact with other metals, should be avoided. Physical contact between the pipe surface and other structural materials of high thermal conductivity will result in heat transfer much greater than that shown in Tables 1 and 2 for transfer from bare pipe to air.

The saving due to use of insulation on piping is illustrated in *Example 4.*

Example 4. If the steam line given in *Examples 1* and *2* is covered with 1 in. thick 85 per cent magnesia, determine the resulting total annual loss through the insulation. Also compute the monetary value of the annual saving and the percentage of saving over the heat loss from the bare pipe.

Solution. By referring to Fig. 1, the coefficient for 1 in. magnesia on a 2-in. pipe is found to be 0.300 Btu per (hr) (linear ft of pipe) (deg temperature difference) at a temperature difference of 169.4 F. The total hourly loss per linear foot of pipe will then be 0.300 × 169.4 = 50.8 Btu. The total annual loss through the insulation = 50.8 × 165 (linear ft) × 4000 (hr) = 33,500 Mb. The annual bare pipe loss as determined in the solution of *Example 1* was found to be 181,600 Mb. The saving due to insulation is then 181,600 − 33,500 = 148,100 Mb per year.

From the solution of *Example 2*, it was found that the heat supplied to the system